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A SYSTEM FOR MONITORING PROTON LOSSES FROM THE NAL MAIN ACCELERATOR*

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June 1, 1973

Summary

The National Accelerator Laboratory (NAL) Main Ring Beam Loss Monitor System employs ~200 inexpensive liquid scintillation detectors distributed evenly around the accelerator circumference to measure radiation created when protons strike vacuum chamber walls, obstructions, magnets, etc. The detectors are interfaced to the computer control system through 10 channel "sample and hold" electronics which also integrate and amplify incoming pulses. Since the computer system can arbitrarily select the times during a machine cycle when sampling will occur, it is possible to generate real time graphs of radiation loss versus time, radiation loss versus machine circumference, or a three dimensional histogram combining the two.

I. Design Criteria

A machine designed for very high intensities, 5×10^{13} protons per cycle in the NAL Main Ring, must operate with the smallest possible beam loss so that residual radiation levels are low enough to permit personnel to safely perform requisite accelerator maintenance. Tolerable exposure rates for this purpose were taken to be 3-100 mR/hr at one foot after one hour of "cooling". A study of beam loss mechanisms, beam loss monitoring requirements and possible detectors, undertaken early in the accelerator design, resulted in the following beam loss system design constraints in addition to the broader, strictly enforced, design philosophy of simplicity, maintainability and economy.[1] A maximum total loss of 0.1% of full design intensity, or 5×10^{10} protons per accelerator cycle, was chosen as a reasonable design goal. It was also specified that over a short time (~1ms) and at a local "point" target the losses should be kept $\leq 10^9$ protons. Taking these intensities at the 8 GeV injection energy (~1 Joule) an estimate was made of the required detector sensitivity.

Two types of detectors were considered: (a) ionization detectors which are inherently reliable, stable, noise free, accurate, and radiation resistant, but are also insensitive ($q \sim 10^{-11}$ coul./liter - atmosphere - Joule estimated for our geometry), have slow response time and require expensive electronics; and (b) photomultiplier-scintillators which have fast response times, high sensitivity ($q \sim 10^{7}$ coul./Joule), but are susceptible to radiation damage and exhibit large sample to sample signal amplification characteristics. Bearing significantly on the final choice of scintallators was the decision that this system would only be required to resolve losses at least an order of magnitude above the more or less evenly distributed losses due to residual gas scattering aroung the ring. Since the radiation produced by a "point" beam loss is localized to about one machine unit cell (~200 feet), a density of one detector per mini straight section; that is, at each 7 ft. quadrupole or every 100 feet, was chosen.

*Work performed under the auspices of the United States Atomic Energy Commission.

The expected modes of operation were to observe one detector throughout a cycle or to scan all detectors at one sample time during the cycle.

II. The Service Building Subsystem

The unit building block is the service building subsystem diagrammed in Fig. 1. A high degree of modularity was imposed and all twenty-four service buildings have nearly identical equipment. A single power supply (Power Designs Model 1565) rated at 0 to 2 kV, 0 - 15 ma, powers all the detectors in parallel via a single RG-58 c/u high voltage distribution cable. Signals from each detector are brought back on individual pieces of RG-58 c/u to the service building beam loss monitor electronics. Analog outputs from the ten channels of this unit are scanned by a Multiplexed Analog to Digital Converter (MADC) under control of the Main Ring mini-computer via the serial data link and local House Logic Unit (HLU).[2] The digitized data is also sent back to the mini-computer via the HLU and serial data link. Beam Loss monitor data from all Service Buildings is accumulated in the mini-computer and then transmitted via a second data link to the Xerox Data System Sigma 3 master computer. The Sigma 3 collates, formats and presents the data on a CRT display and/or a Tektronix 611 storage scope as requested by the operator.[3]

The Detectors

The "Paint Can" scintillation detectors were originated by the NAL Radiation Physics section.[4] Consisting of a 931A photomultiplier tube mounted on the inside of the lid of a paint can partially filled with liquid scintillator, the detectors are extremely simple, economical, and easy to build. Further simplifying modifications were made for the Main Ring installation. An RCA developmental tube, type C31028, equivalent to their present 4552, replaced the 931A. C31028's are all glass with no base material to dissolve in and possibly poison the scintillator. They are also cheaper and physically short enough to fit in a one pint paint can while mounted in a tube socket - see Fig. 3. The voltage divider string of 11 100kΩ resistors draws ~1.4mA at 1500V so that 10 cans can be operated from a single HV supply. The divider has no capacitors across the dynode resistors, but no sag has been encountered since maximum count rates always produce less than 0.1mA anode current. The anode is brought out directly to a BNC with no load resistor to ground, which allows dc measurements of dark current and gain. Each can was filled to 75% of volume with a high flash point mineral-oil base scintillator, "Pilot HF".[5]

For a slight extra cost the manufacturer supplied a measurement of luminous sensitivity for each tube. The variation in received tubes was 10 to 1, 200A/lm to 20A/lm. At NAL subsets of ten tubes were matched in dark current and gain to within a factor of 2 or less at 900 - 1100V. For final selection, gains were measured with the paint can installed in the tunnel using a 100μ curie Co^{60} source in a fixed geometry. The gains

Presented at the 1973 Particle Accelerator Conference

of the matched subsets were then adjusted by varying the power supply voltage in each service building so that the overall gain variation of all detectors in the ring remained within the factor of 2.

Electronics

By deciding to not look at fast pulses through service building electronics, but to display phototube output from the 50Ω terminated cable directly on a oscilloscope, considerable circuit simplification results. The electronics were designed to perform three basic functions: (1) act as an integrator over observation times ≤10ms, (2) act as a signal averager over periods >10ms and (3) take a 100μ sec sample of the processed signal and hold it with a droop of <1% in output voltage for the 100ms or so required for the minicomputer to respond to an interrupt and retrieve all data from the Service Buildings.

A block diagram of the beam loss monitor electronics can be seen in Fig. 2, and a picture of the unit in Fig. 3. The "Input Conditioning" circuit consists of a series 47Ω resistor connecting the incoming RG-58 across a 100kΩ resistor, an integrating capacitor and a protective zener diode, all shunted to ground, to the front panel control switches. The dc coupling of the paint can's anode output permits use of the cable shunt capacitance as part of the total integration capacitance. The amount of capacitance added to each input conditioning circuit is selected to bring the total up to that of the longest cable, ~550 ft., plus lnf. The series input 47Ω resistor is then always followed by a capacitor to ground which ensures an ac 50Ω termination to nanosecond phototube pulses. The gain-of-5 voltage follower stage is a National Semiconductor LM308 with an i_{bias} of <20nA.

The Sample and Hold amplifier is a National Semiconductor LH0023CG hybrid integrated circuit which could be purchased cheaply enough in quantity to make this form of circuit design economically feasible. The 10 channel analog OR Input comparator shown in Fig. 2 serves as an out-of-limits trip when excessive radiation is recorded on one or more input channels. A fault condition latches the Set-Reset flip flop which is intended to trip and latch the Main Ring Abort System until the start of the next cycle when it will be cleared by a Main Ring Reset, the t_0 pulse. Delays on the Beam Sample Pulse input were to allow this electronics to be used in other applications were it might be desirable to sample a voltage simultaneously around the ring,. without the usual 48 μsec propagation delay. The Variable Gate Width Monostable generates a 100 μsec sampling time gate required to ensure that the sample and hold outputs slew to within 1% of input voltage.

The distribution of detectors leaves one spare analog channel in each Service Building available for monitoring output of the high voltage power supply. During maintenance the front panel control switches allow for a quick check of zero offset adjustments, gain drift, amplifier failure or MADC failure. A stroll around the tunnel with a source while continuously monitoring paint can amplitudes versus circumference provides a simple, calibrated check of the entire system which takes a little over an hour.

III. System Operation

The beam Loss Monitor System was one of the first beam diagnostics placed into operation in the NAL Main Ring and, together with scintillator target flags, provided the only beam information available during the summer of 1971 while tuning for a first turn around the Ring. A continiously updated storage scope plot of Beam Loss as a function of machine circumference was used together with small correction magnets to tune for minimum local beam loss. Since correlation between a specific correction dipole and a high loss peak was difficult to establish, the system diminished in importance as more suitable and sensitive beam diagnostics became available. Finally, six sample and hold channels at each service building were preempted for voltage to ground measurements on the Main Ring power supply system. This was facilitated by a design feature of the electronics module: conditioning circuitry for all inputs is located on a separate printed circuit card to permit rapid modification. The recent acquisition of 30 additional electronics chassis, now called "Utility Sample and Holds", will permit the reactivation of the complete beam loss monitoring system. Even though four detectors privide less than adequate coverage, they are still quite useful. Continuousmonitoring of areas of suspected or known loss can be monitored via a high sample rate mode in which up to 300 beam sample pulses are generated over a Main Ring cycle or selected subportion thereof. A plot of loss amplitude versus time for one detector is generated on a Tektronic 611 Storage Scope by the Sigma 3 computer. A typical plot is shown in Fig. 4.

IV. Conclusion

During its variegated career the Beam Loss System has demonstrated the ability to locate partially collapsed vacuum tubes, obstacles in the beam pipe and closed vacuum isolation valves. Now that the intensity of the accelerator has become $>10^{12}$ protons per cycle, it is expected that the beam loss monitor system will play an increasingly important role in helping to tune the machine for minimum beam loss, and therefore, minimum residual radiation.

Acknowledgements

Of the many members of the NAL staff who have participated in various phases of equipment design and development, most of whom are mentioned in the references, particular thanks are due to Mr. Robert Kolar who was responsible for most of the initial calibration, testing, installation and maintenance of the hardware.

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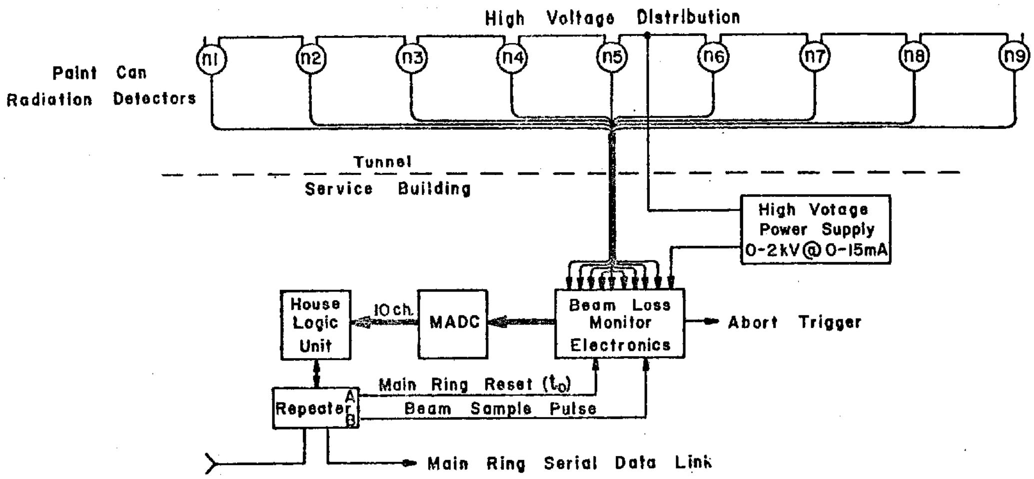

Fig. 1. A Main Ring Service Building Beam Loss Monitor Subsystem configuration. Paint can detectors are identified by tunnel survey marks n1 through n9, where n specifies service buildings, 1 through 4 per Main Ring sector. n1 detectors exist only for n = 1,2 service buildings. These configurations are identically repeated in Main Ring Sectors A through F.

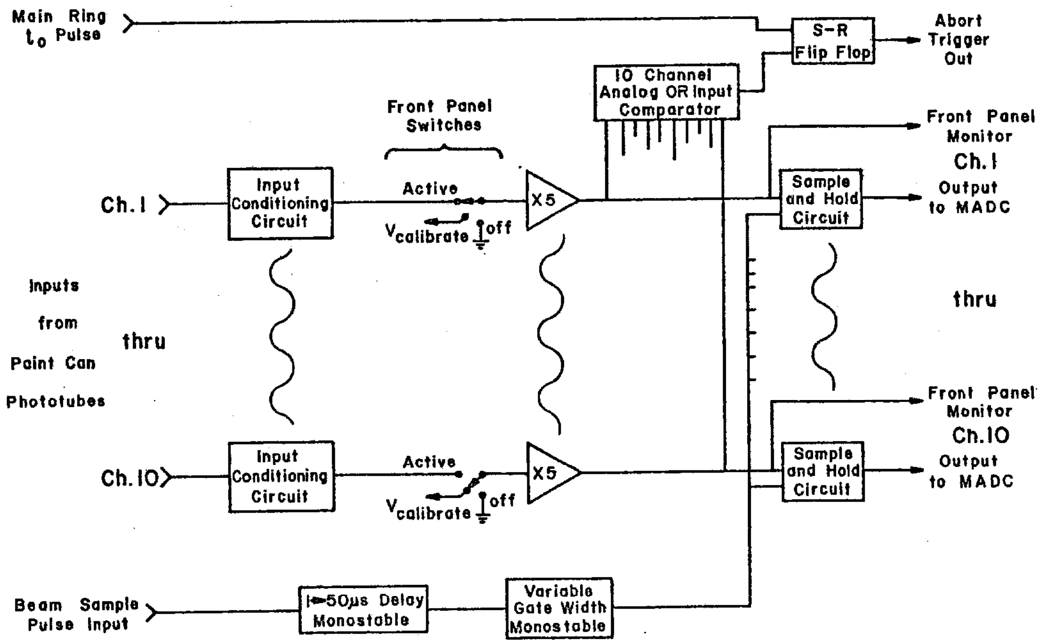

Fig. 2. Beam Loss Monitor System Service Building Electronics.

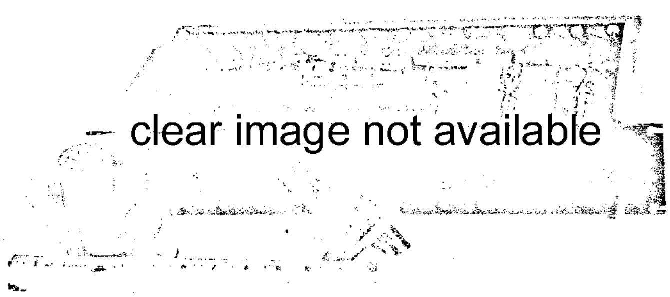

Fig. 3. Paint can scintillation detector and 10 channel sample and hold electronics.

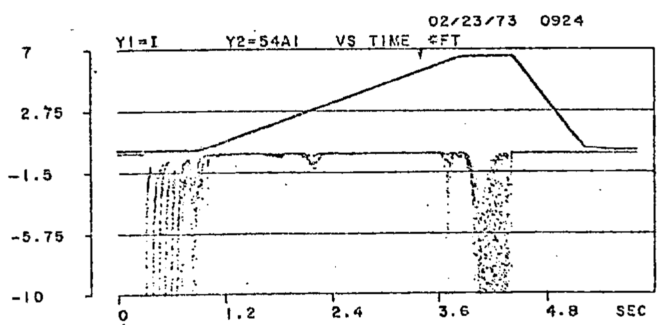

Fig. 4. Computer generated plot of beam loss and magnet field amplitude versus time.